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SUPERFICIAL CRACKING OF PEPPER FRUITS

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SUPERFICIAL CRACKING OF PEPPER FRUITS

BY

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SECTION I

INTRODUCTION

A defect of fruits of the pepper, Capsicum annum L. has been observed among varieties and breeding lines of this crop grown at the Horticultural Farm, Durham, N.H. When severe, this defect has altered the appearance and quality of fruits sufficiently to render them unmarketable. It can be described as a superficial cracking of the fruits. Preliminary observations of the abnormality were made in 1962. It seemed to be sufficiently serious the following year to warrant a more thorough study. The present study was made to record and describe the abnormality, to survey the extent of superficial cracking of fruits among some commercially available varieties of pepper, to search for cracking resistance, and, by analysis of segregating populations, to determine whether susceptibility to the defect might be a heritable characteristic.

SECTION II

LITERATURE REVIEW

No reference to superficial cracking of pepper has been found in the literature. A rather complete bibliography of the pepper through 1964 has been published by Lippert and Scharffenberg (5). Since 1935, various types of cracking of the tomato, another member of the Solanaceae family, have been given much attention by research workers. Hepler (4) summarized the work on cracking of tomatoes previous to 1961 and contributed to the knowledge of this problem by an objective analysis of his own. The physiological disorder of tomato manifested as cracking was classified as: radial, concentric, burst, and cuticle cracking. The factor most often associated with fruit cracking was a water relationship. Cracking is sporadic in its occurrence. It can be serious one year and not in another. He concluded that cracking in the tomato was of an heritable nature with gene action that was additive, partially dominant, and sometimes dominant being indicated.

Niiuchi (8) stated that resistance to cracking of tomatoes is associated with thick foliage shading of the fruits, extensibility of the fruit skin, low sugar content of fruits, and a low degree of suberization of the fruit.

Graftage of peppers was reviewed since reciprocal grafts of healthy and abnormal plants have been resorted to for study of transmission of infectious diseases of plants. Following grafting of two pepper varieties, Yagishita (14) reported modifications in the shape of fruits. After growing two self-pollinated generations of seedlings from seeds borne in modified fruits, he concluded that the altered shapes persisted in both generations. In another paper, Yagishita (15) found no variation in fruit shapes "after two generations of grafting",

but mentioned that multiple grafting (successive?) has a cumulative genetic effect. However, Ohta (10) could not demonstrate any changes in the F_1 or F_2 following grafting of plants having distinctively different genetic constitutions. Topernina (12) published a paper on graftage of peppers. His scions were defoliated, so all nourishment came from the stock. He reported some marked variations in seedling progenies grown from the fruits harvested from the scion variety.

SECTION III

MATERIALS AND METHODS

I. Greenhouse experiments

A. Source of pepper varieties. Seed of pepper varieties were received from several sources:

a. Joseph Harris Co., Moreton Farm, Rochester, New York: Allbig, Calwonder, Cubanelle, Delaware Belle, Harris' Improved Squash, Hot Portugal, Hungarian Wax, Italianelle, Keystone Resistant Giant, Large Red Cherry, Pennwonder, Red Cayenne, Staddon's Select, Vinedale, and Yolo Wonder B.

b. Farmer Seed & Nursery Co., Faribault, Minnesota: Acanqua, King of The North, Large Bell, Morgold, Sweet Cream, and Wisconsin Lakes.

c. Burgess Seed & Plant Co., Galesburg, Michigan: Golden Wonder, Michigan Wonder, Pacemaker, Red Chili, and Sweet Cherry.

d. Eastern States Farmers' Exchange, West Springfield, Massachusetts (Agway Inc., Syracuse, New York.): Eastern Rocket, Green Boy Hybrid, and Italian Sweet.

e. Letherman's, Inc., Canton, Ohio: Sweet Roumanian.

f. Gill Bros. Seed Co., Portland, Oregon: Large Sweet Yellow.

g. Associated Seed Growers, Inc., New Haven, Connecticut (Asgrow Seed Company International, Milford, Connecticut.): Floral Gem.

h. Department of Plant Science, University of New Hampshire, Durham, New Hampshire: Merrimack Wonder, Nosegay, Pinocchio, and Sweet Chocolate.

i. Department of Vegetable Crops, University of California, Davis, California: UC# 61 M 10, and Santa Fe Gem.

j. Vegetable Crops Division, University of Illinois, Urbana, Illinois; Ill. # 1003-201, and Ill. # 1003-205.

k. Department of Horticulture, Michigan State University, East Lansing, Michigan; Spartan Emerald.

l. Northeast Regional Plant Introduction Station, Geneva, New York: Plant Introduction Numbers 263073 (USSR), 263078 (USSR), 263109 (USSR), 263110 (USSR), 263114 (USSR), 267081 (USSR), 264659 (Germany), 264662 (Germany), 260453 (Argentina), and 286419 (Nepal).

In addition, a true-breeding line of pepper and a variety developed at the New Hampshire Agricultural Experiment Station were used in this study: namely, NH# 59-4 and Permagreen.

B. Growing the seedlings. Seeds treated with Arasan (tetramethylthiuram disulphide) were sown in clean sand in wooden flats. The flats were placed in a warm greenhouse to allow the seeds to germinate. The seedlings were transplanted into 3- inch standard clay pots or wooden flats as soon as they showed their first true leaf. A soil mixture made up of 3 parts of good greenhouse bench soil (one part compost soil, 1 part of sand and 1 part of peat) and 1 part of dried cow manure was used for this purpose. After the plants had grown for a month, they were transplanted into 6- inch standard clay pots for further observation in the greenhouse.

C. Technique of crossing. Pepper plants to be used for breeding were removed from the field during late September or early October and placed in a warm screened greenhouse. The plants were pruned lightly before they were transplanted into 10- inch standard clay pots containing a soil mixture as described above. The same day that the pepper plants were moved into the greenhouse, they were put under lights to give them supplemental illumination after sunset so as to approximate a 15- hour photoperiod. One-hundred-watt Mazda incandescent bulbs with reflectors, spaced 4 feet apart over the bench,

furnished the necessary light and were controlled by an automatic electric timer. Greenhouse temperatures were maintained at approximately 70° F. during the day and 60° F. at night.

As soon as they became large enough, healthy flower buds were emasculated by removing the stamens with forceps approximately one day before anthesis. A hand lens or Magnifier was used to make sure that no pollen had been shed.

Emasculated flowers were pollinated the same day and also on the following day. Every pollinated flower was marked by placing a tag on the pedicel. The pollen parent and the date of pollination were recorded on the tag. Fruits resulting from hand pollinations were harvested when they were fully ripe. Seeds removed from fruits were air-dried for 1 or 2 days and then stored at 0° F. for 1 or 2 weeks. Progenies of both hybrid and self-pollinated seedlings were grown.

D. Seeds for F_2 generation. First-generation plants were grown in an insect-proof screened greenhouse to insure self-pollinated seeds for the F_2. While the pepper is classified commonly as a self-pollinated crop, Odland and Porter (9) found as high as 37 percent natural crossing in field-grown seeds when certain varieties were planted in close proximity.

E. Grafting experiments. In the summer of 1963 graftage was used to determine whether superficial cracking might be transmitted from one plant to another plant. Reciprocal grafts were made between Sweet Roumanian and Large Sweet Yellow varieties. Sweet Roumanian had shown serious cracking and Large Sweet Yellow was assumed to be free from the abnormality at that time. Seedlings of the 2 varieties having stems about 1/4 - inch in diameter were grafted July 21, 1963. A cleft graft was used with procedure as follows: first, the top of the stock plant was cut off 2 to 3 inches from the soil. The top of the cut

stem was split at the middle about 1 inch deep. An actively-growing top portion of a seedling with several attached leaves was chosen for a scion and its base was bevelled on two sides and inserted in the stock. The scion was held tightly in place with a rubber strip. All grafted plants were held in a cool, humid, shaded greenhouse for about 5 days. The plants were watered every day. After 5 days all grafted plants had made successful unions. The grafted plants were transplanted into 6-inch standard clay pots and placed again on a bench in a warm screened greenhouse. They were spaced 14 inches apart between the rows and 12 inches apart in the rows so that they could be given regular care and kept under close observation.

2. Field Experiments

Pepper seedlings for transplanting to the open field at the Horticultural Farm, Durham, N. H. were started in the greenhouse and grown according to methods previously described. In 1964, seeds were sown April 10, the seedlings transplanted into 3-inch pots or wooden flats April 28 and 29, and transplanted to the field plot on June 1. Because of drought conditions, it was necessary to irrigate the plants by an overhead irrigation system on June 2. The plants were spaced 1.5 feet in rows that were 3.5 feet apart. The soil in this area has been classified as the stony phase of Paxton. Before plowing, 10 tons to the acre of cow manure supplemented with 400 pounds of superphosphate were applied to the area. Between 400 and 500 pounds per acre of a commercial brand of 10-10-10 fertilizer were broadcast and harrowed into the soil.

In 1965, another nearby plot on similar type soil prepared in a similar manner was chosen for planting to peppers. As the season seemed delayed somewhat, seeds were not sown in the greenhouse until April 16. Seedlings were transplanted on April 28 and 29 and set in the open field on May 28. Seedlings were spaced at the same distances as in 1964. In both years, one or two applications of one percent Rotenone dust were

used to control flea beetle, Crepidodera species. No other dusts or sprays were applied at any time. Shallow cultivation and frequent hand hoeing were done as needed to maintain the plots free of all weeds. No fruits were picked from the plants until a single harvest was made just before or soon after the first killing frost late in September. After all the fruits, both immature and ripe, had been picked from a plant and laid on the ground beside the plant, the fruits were observed carefully and rated for the amount of superficial cracking that had occurred. Weather records for the two growing seasons are listed in the appendix.

3. Rating system for fruits

After the fruits from a single plant had been harvested, they were divided into 2 groups consisting of immature and ripe peppers. Any fruit that had not turned completely to the color characteristic of that variety when ripe (red, yellow, brown, or dark green for the Permagreen variety) was classified as immature. Those fruits free of superficial cracking in each of the groups classified as to maturity were separated and counted. All fruits showing the defect were rated individually by a visual rating system, with a 0 value for freedom from cracking and values from 1 to 9 representing various severities of the trouble. The most severe rating had a value of 9. After counting the number of defective, cracked fruits among those grouped as immature and those grouped as ripe, a weighted mean visual rating for each plant was computed. Five plants of a variety that had been rated individually were then pooled to ascertain a mean rating for both the immature and the ripe fruits of the variety. Individual seedlings in F_1 and F_2 populations were rated in a similar manner.

4. Photographs

A Bausch and Lomb Stereo Zoom series A microscope was used to photograph the surface of fruits under magnification. Other photographs were taken by use of a Contaflex single lens reflex camera adapted to photograph at distances of 0.2 to 0.5 meter. Kodachrome II daylight color film was used.

5. Statistical Methods

A. Least-squares analysis. Comparisons of 26 varieties, which were grown in 1964 and again in 1965, were made by using least-squares analysis for data with unequal subclass numbers in a two-way classification with interaction (3). There were 5 plants of each variety. Data were analyzed separately for the ripe and immature fruit groups. The statistical analyses were made by use of an International Business Machine 1620 Computer available in the University of New Hampshire Computer Center.

B. Warner's method for estimating heritability. According to Warner's proposal (13), the heritability estimate is based on total variance of the F_2 and the backcrosses of the F_1 to each inbred parent. No estimate of environmental variance or of total genetic variance is necessary. Use is made only of total within-population variances. Heritability is calculated by the following formula:

$$\text{Heritability} = \frac{(1/2)\,D}{V_{F_2}}$$

$(1/2)\,D$ = the additive genetic component of variance of F_2

and V_{F_2} = total within variance of F_2

and $(1/2)\,D = 2\,(V_{F_2}) - (V_{B_1} + V_{B_2})$, where

V_{B_1} and V_{B_2} are the total within variance of backcrosses of the F_1 to the respective parents.

As stated by Warner (13):, "The method is based on the conventional assumptions in estimating heritability, whether by parent-offspring regressions or by components of variance, i. e., additivity of genic effects, locus to locus (no epistasis), and independence of genotype and environmental variance. An additional assumption is necessary to the effect that the environmental components of variance of the F_2 and of the two backcrosses are of comparable magnitude."

SECTION IV

RESULTS AND DISCUSSION

1. Description of superficial cracking of pepper fruits

Superficial cracking of pepper fruits occurred both in the field and in the greenhouse. As no previous report or description of the abnormality has been published, photographs illustrating defective fruits are included in this study. A photograph of tomatoes is presented showing similar sympotoms. The tomato plants having the cracked fruits grew in a row adjacent to pepper plants grown in the open field in 1963. Thompson and Kelly (11) have stated that pepper and tomato have similar cultural, climatic and soil requirements and that several diseases of the pepper are the same as or similar to those of the tomato. Brown and Price (1) reported that only very immature green tomato fruits were consistently free of cracking. The same conclusion can be stated for pepper fruits as observed in the present study.

Very fine superficial cracking of fruits could be detected by close observation of an advanced stage of green fruit development. Such fruits would be considered ready for harvesting commercially for use as green salad peppers. In fact, the abnormality was found present on green peppers that had been shipped in from southern states to local city markets. Incipient superficial cracking of the fruits can be identified under direct bright light by use of a hand lens for magnification before it becomes readily apparent otherwise. With reference to Figure 1, typical superficial cracking of fruits of a plant of NH # Y-61 pepper, which has ripe yellow fruits, is clearly evident on both immature and ripe peppers. Subcuticular cells in the flesh of the fruit as well as the cuticle had been ruptured. Following suberization of the

minute wounds, the abnormality became prominent. The surface of the fruit was rough from formation of cork tissue.

A. Varying patterns of cracking. Figure 2 is a photograph of the superficial cracking at 10.5 magnification. Marked variation in size of the cracks can be seen. Most of these cracks are longitudinal. In Figure 3, longitudinal cracks on a fully ripe red fruit are most prominent, although a few at right angles to the main axis of the fruit can be found, particularly near the blossom end. In Figure 4, severe cracking shows at the blossom end of a fruit. In Figure 5, both longitudinal and transverse cracks appear at the stem end of fruits, and both the lobes and depressed area between the lobes are affected. Apparently any portion of the surface of the fruit can develop superficial cracking. The pattern of cracking may differ according to varieties. The varieties studied had a series of color variations in the immature fruits varying from a light sulphur yellow through light green to a deep dark moss green color typical of the Permagreen variety. Cracks were observed with difficulty on sulphur yellow fruits as they did not contrast with the color of the immature fruit. Superficial cracking was most readily observed on ripe red fruits. These facts had to be taken into consideration when ratings of the relative amount of cracking of fruits were made.

The pattern of cracking in peppers can not be classified so readily into distinct types as has been done with the tomato by Hepler (4). Typical bursting of fully ripe pepper fruits was observed in the field in this study following a rain of 0.75 inch on September 13, 1965 that had been preceded by 4 weeks of inadequate moisture supply for the plants. The photograph of a defect of tomatoes grown in this study (see Figure 6) can be described as another case of superficial cracking of the fruit. Some might refer to the condition both in tomato and pepper as "russet". In the strict sense of the word russet is a color, and certain winter varieties of apple having a rough skin are called russets

because of their color. Superficial cracking affects pepper fruits regardless of their size, provided that they have attained a certain stage of maturity.

Figure 1. Superficial cracking of NH # Y-61 pepper fruits in 1963.

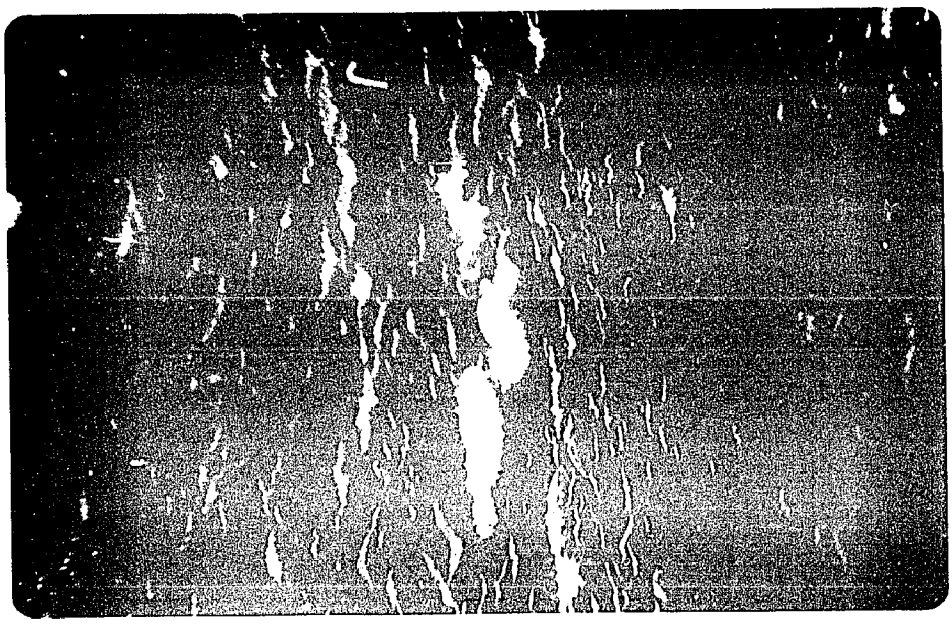

Figure 2. Superficial cracking of a fruit of an unnamed N. H. pepper selection X 10. 5 magnification.

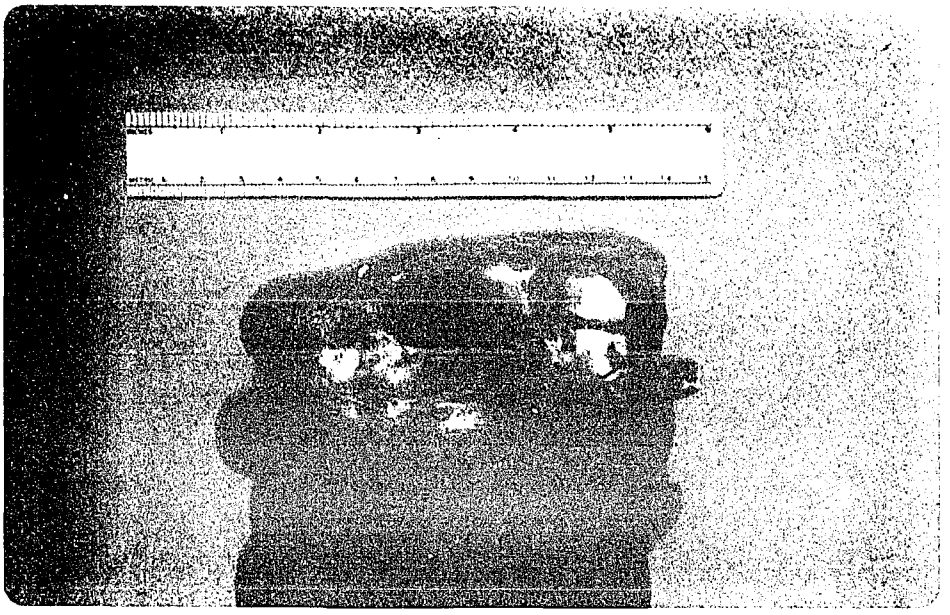

Figure 3. Superficial cracking of a ripe fruit with most cracks being longitudinal. NH # Y-61 X Sweet Roumanian F_1.

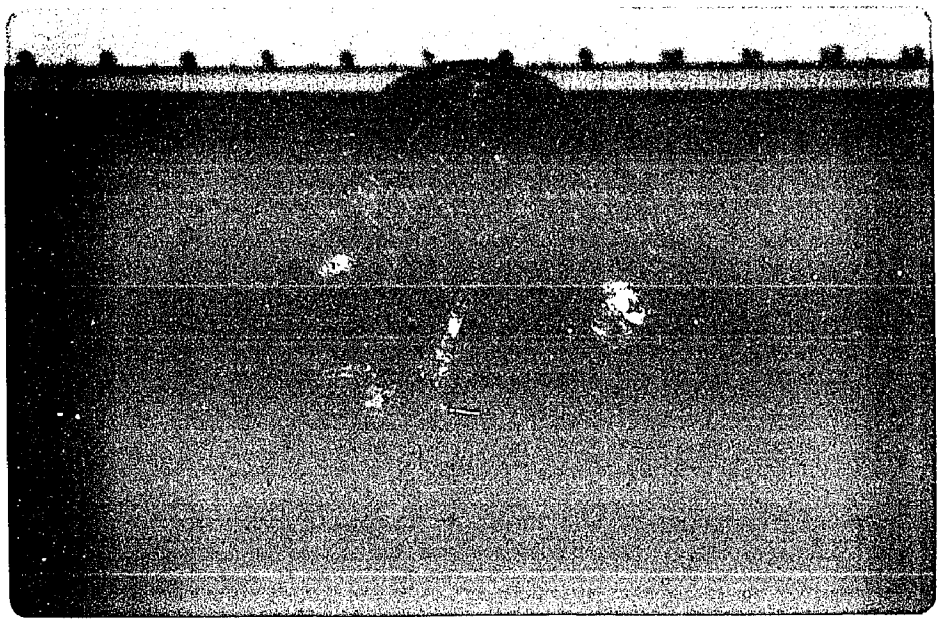

Figure 4. Superficial cracking located at the blossom end of a ripe pepper fruit. Calwonder variety.

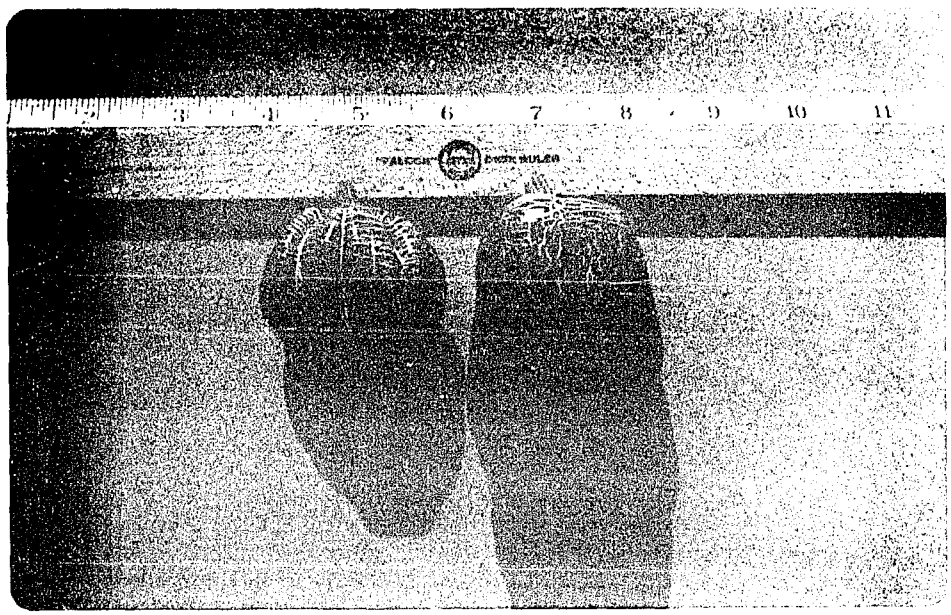

Figure 5. Both longitudinal and transverse cracks at the stem end of fruits. Greenhouse-grown Sweet Roumanian.

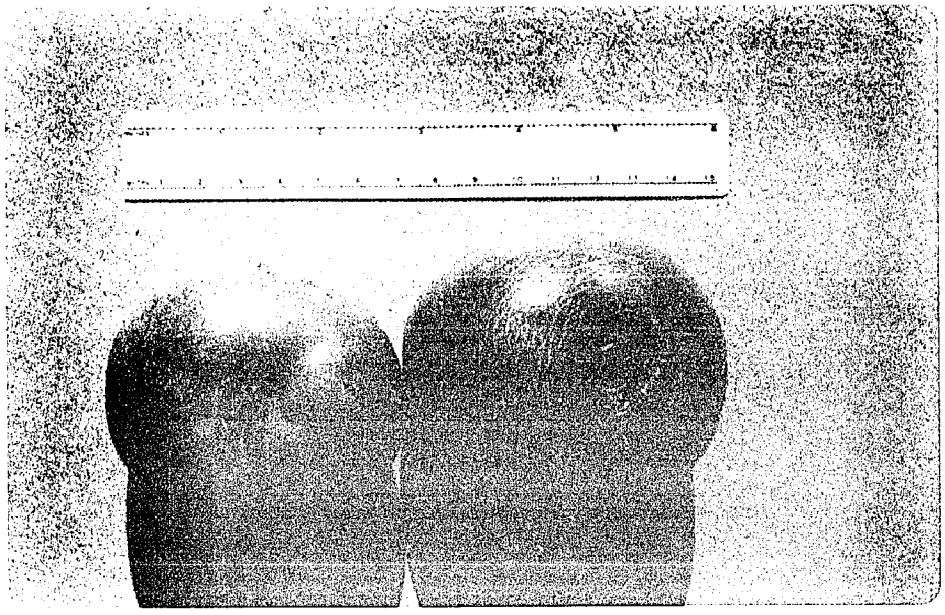

Figure 6. Superficial cracking of tomatoes.

B. Parthenocarpic fruits. Some seedless fruits ripened both in the greenhouse and the field. Curtis and Scarchuk (2) reported the occurrence of seedless fruits in pepper to be a recessive character depending on a single Mendelian trait. Both parthenocarpic and normal fruits grew on the same plant in this study. Marked differences in the size of ripe fruits resulted as illustrated in Figure 7. Regardless of size of fruits, after they had reached the proper stage of maturity, superficial cracking of the relatively small parthenocarpic fruits occurred. The pattern or type of cracking could not be distinguished from the defect on normal fruits. Both green and fully ripe parthenocarpic peppers had superficial cracking.

C. Incidence of cracking. As grown in the field, particularly in 1965, some peppers set from flowers borne so close to the ground that, when the fruit enlarged, part of it came in contact with the moist soil. When the fruit was one that had superficial cracking, the portion of the pepper contacting the ground was more severely affected than other parts of the surface of that fruit. Severe superficial cracking of a fruit resulted also when a moist dead leaf stuck to the surface of the fruit. The portion covered by the leaf was severely affected. Superficial cracking of pepper fruits is associated with moisture relationships.

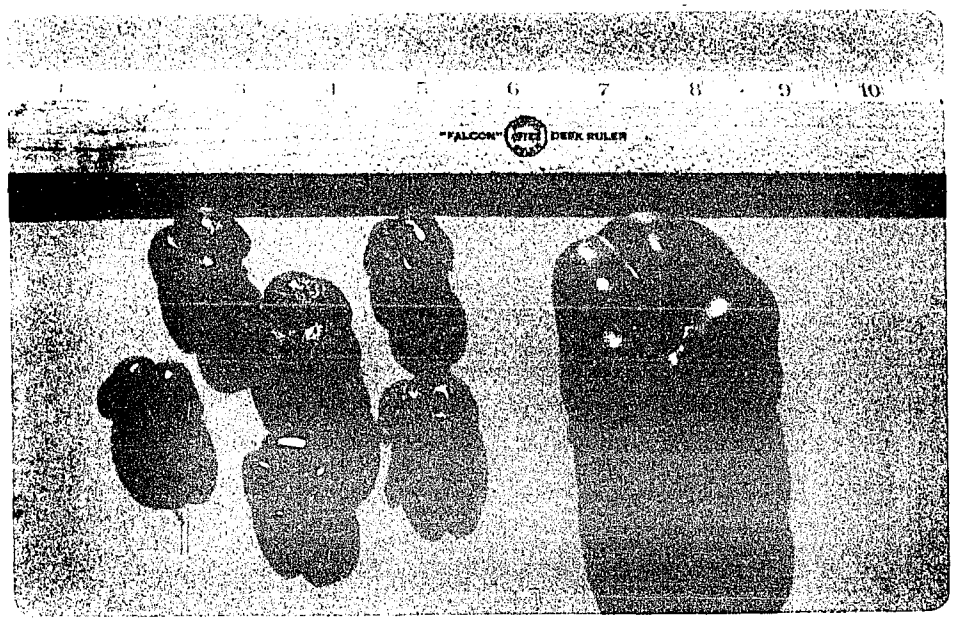

Figure 7. Small parthenocarpic fruits and a normal ripe fruit matured on the same plant. Greenhouse-grown NH # 59-4 X Sweet Roumanian F_1.

2. Observation of grafted plants

A pepper plant that had been grafted and then grown in the greenhouse until a fruit had ripened is illustrated in Figure 8. The purpose of graftage differed from that of Yagishita (14) (15), Ohta (10), and Topernina (12) who were primarily interested in determining genetic effects. In this study, it seemed feasible to make reciprocal grafts of two varieties of peppers, one of which was subject to severe superficial cracking and another that might be free of the defect. This method should test whether the abnormality might be associated with a virus or any transmissible pathological condition. Two varieties that had ripe fruits of a contrasting color were used so that there was no chance to confuse identity of the kind used either as a rootstock or as a scion. Sweet Roumanian had red ripe fruits and a rating for severe cracking when grown in the field (see Table 1). Large Sweet Yellow pepper matured yellow fruits, but it was found, after the grafts had been made in the greenhouse, to be also somewhat subject to cracking in the field (see Table 2). Regardless of this fact, the relative susceptibility of the Sweet Roumanian and Large Sweet Yellow varieties to superficial cracking was maintained without discernible change in 40 plants that had been grown as reciprocal grafts. The amount and pattern of cracking was characteristic of the variety regardless of whether it was nourished by its own roots or was grown on a rootstock of the other variety. No pathological condition transmissible by the sap of the plant through a graft union was observed. Superficial cracking of fruits was considered to be a noninfectious disorder and possibly one that might be inherited.

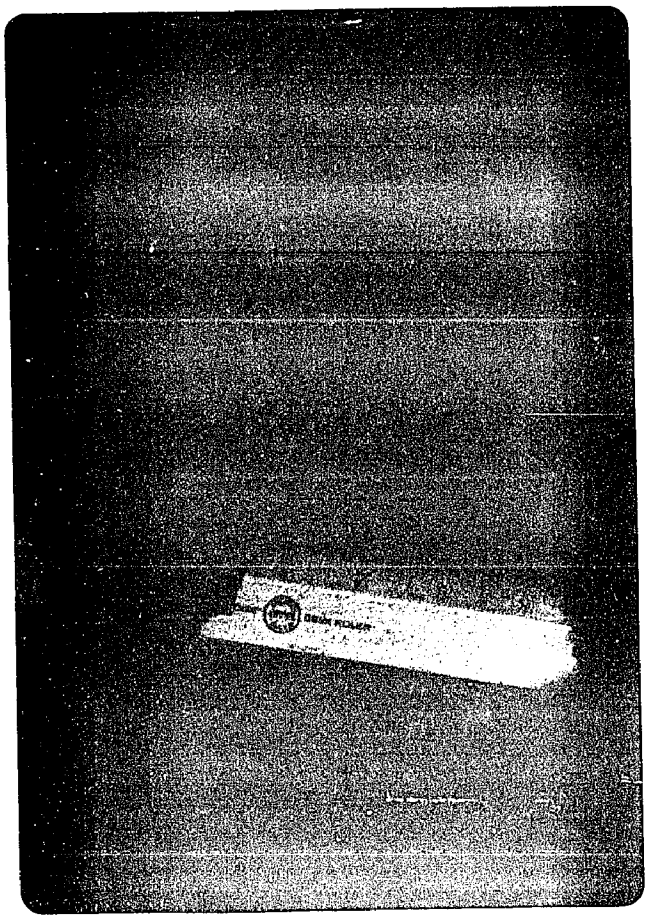

Figure 8. Sweet Roumanian pepper grafted on Large Sweet Yellow variety as a rootstock.

3. Freedom from cracking

Cursory observation was made in 1962 of peppers grown in plots at the Horticultural Farm, Durham, N. H. After an examination of unharvested fruits, it seemed that Keystone Resistant Giant, Large Sweet Yellow, and breeding line NH # 59-R were free from the defect. In 1963, all three kinds had superficial cracks. Breeding line NH # 59-4 seemed free of cracking in 1963, but when examined in 1964, it could not be rated entirely free of the defect. Of all varieties surveyed (see Table 1) only one variety, Red Chili, had a 0 rating and has remained free of the defect. It is a pungent variety. Thirty-one sweet varieties were found to have superficial cracking of varying severities. Through the courtesy of Mr. Walter S. McIlhenny, president of McIlhenny Co., Avery Island, Louisiana, a potted pepper plant with mature ripe fruits such as are used for making Tabasco brand pepper sauce was shipped to Durham, N. H. in October, 1965. Repeated crops of ripe fruits were observed in the greenhouse before the plant was discarded in spring of 1966. No cracked fruits were seen. Of nine other varieties of pungent peppers listed in Tables 1 and 2, all had some cracking. No direct relationship between size, shape of fruit, or presence or absence of capsacin, which is the pungent substance in peppers (6), and superficial cracking of fruits was found.

4. Implications from ratings for cracking

Morrow, Darrow, and Rigney (7) pointed out that scores or ratings given horticultural material could be handled just as any objective measurements to give means and standard errors. Such ratings can be subjected conveniently to standard methods of statistical analysis. The mean ratings of the immature fruits for 26 varieties of peppers

grown both in 1964 and 1965 (see Table 1) seemed to have less superficial cracking than the ripe fruits. Both stages of fruit maturity were given lower ratings in the first year than in the following one. When the data were treated by the method of least-squares (see Table 4), statistical significance was found for differences between varieties, years, and varieties x years. The tendency for more cracking to result as the fruit progresses from the green stage of maturity to full ripeness is clearly evident. In the case of the Permagreen variety, which remains the same green color regardless of the stage of maturity of the fruit, there is no reason for making an exception. It was not included in the tables because of the difficulty of ascertaining precisely its degree of ripeness which was the criterion used with all other varieties for separation into 2 groups of fruits. The unclassified fruits of Permagreen, the majority of which were at or nearing full ripeness, were rated 2.2 and 3.4 for superficial cracking, respectively, in the two years.

Twenty-three varieties included in the survey for cracking of fruits proved too late for New Hampshire (see Table 2). Because most of them had no ripe fruits in 1964, they were not planted in 1965. All 23 kinds had superficial cracking of the immature fruits. Sweet Cream variety, grown only in 1965, had relatively high ratings of 5.2 and 6.8 for immature and ripe fruits, respectively.

As cracking of fruits of the pepper varieties included in this study is so common, the question may arise as to why the defect has not been reported previously. This may be due, in part, to the fact that so many peppers are harvested for green salad peppers, when the incipient superficial cracking would be hardly noticeable. This condition would not, in itself, lessen the sales value of the fruits. Repeated harvestings of salad-type peppers are made. Reduction of load of fruits on a plant may affect favorably water relationships of the plant so that cracking is less serious even in the ripe fruits. Further experiments beyond the scope of this study are needed to learn the causes of

this defect. That the abnormality can become serious when all fruits are left for a single harvest made just before the first fall frost was established in this study. With consideration of the likelihood of machine harvesting of peppers within the next decade from plants on which the fruits have been "stored" for a period of time previous to a once-over harvest, it is probable that the problem of superficial cracking of fruits may assume more importance.

A. F_1-hybrids. When 16 F_1 plants of NH # 59-4 x Sweet Roumanian were grown in a screened greenhouse in 1963 to insure an ample supply of known self-pollinated seed for F_2, all of them had superficial cracking of the fruits. They were not scored for the defect numerically, but the amount was recorded "heavy". Five reciprocal F_1 hybrids of this cross grown in the field in 1965 (see Table 3) in like manner had superficial cracking rated 4.2 for immature fruits and 3.5 for ripe fruits. It is doubtful that any real difference in cracking of the fruits at the two stages occurred. Reciprocal crosses of Sweet Roumanian and Red Chili (see Table 3) had identical ratings of 1.6 for immature fruits and 2.1 for ripe fruits. Of particular interest is the fact that when 2 varities having severe cracking, namely, Sweet Roumanian and Sweet Cherry (see Table 1) were crossed with Red Chili having a 0 rating, the reciprocal F_1-hybrids (see Table 3) all had some superficial cracking. None of the F_1-hybrid plants equaled the relatively severe rating of their parents and none were free of cracking like the Red Chili variety.

Table 1. Weighted mean ratings of superficial cracking for fruits of 26 field-grown pepper varieties in 1964 and 1965.

Name of variety	Ratings for superficial cracking			
	1964		1965	
	Immature	Ripe	Immature	Ripe
Sweet Roumanian	2.0	3.4	6.3	6.0
UC # 61 M 10	1.3	5.3	3.8	5.6
Hungarian Wax	1.9	3.2	5.4	5.4
Sweet Cherry	4.5	5.0	---	4.7
PI. # 263114	0.9	1.8	5.0	4.6
NH # 59-4	1.0	1.3	3.8	3.3
Wisconsin Lakes	1.4	1.0	---	3.2
Italianelle	0.7	1.3	---	3.1
Morgold	1.0	2.0	2.5	3.1
Santa Fe Gem	0.5	3.7	2.5	3.0
PI. # 267081	2.7	2.3	---	3.0
Red Cayenne	0.2	0.1	2.7	3.0
Pinocchio	0.3	1.3	2.9	2.9
PI. # 260453	0.7	1.1	2.8	2.9
Staddon's Select	2.0	---	---	2.8
Pacemaker	0.3	0.2	2.8	2.6
PI. # 263109	0.5	1.0	2.0	2.5
Large Red Cherry	0.0	0.6	1.7	2.4
Eastern Rocket	0.0	0.1	2.2	2.3
Vinedale	2.0	3.4	---	2.2
King of The North	1.1	2.0	2.5	2.0
Sweet Chocolate	0.1	0.5	4.2	2.0
Calwonder	1.2	---	2.8	1.8
Italian Sweet	0.8	0.3	---	1.6
Hot Portugal	0.7	0.5	---	1.5
Red Chili	0.0	0.0	0.0	0.0

Table 2. Weighted mean ratings of superficial cracking for 23 field-grown varieties which matured either very few or no ripe fruits in 1964.

Name of variety	Ratings for superficial cracking	
	Immature fruit	Ripe fruit
PI. # 263073	3.6	---
Ill. # 1003-205	3.2	---
PI. # 263076	3.0	3.6
Allbig	2.4	---
PI. # 264659	2.1	---
Keystone Resistant Giant	2.0	---
Yolo Wonder B.	1.8	---
Large Sweet Yellow	1.8	---
Ill. # 1003-201	1.6	---
Delaware Belle	1.6	---
Green Boy Hybrid	1.5	---
Harris' Improved Squash	1.5	2.4
Michigan Wonder	1.2	---
Merrimack Wonder	1.2	---
Large Bell	1.1	---
PI. # 286419	1.1	0.3
Floral Gem	0.9	2.1
PI. # 263110	0.6	0.5
Pennwonder	0.5	---
Golden Wonder	0.5	---
Cubanelle	0.4	2.9
Spartan Emerald	0.3	---
Acanqua	0.2	---

Table 3. Weighted mean ratings of superficial cracking for 5 first-generation hybrid field-grown peppers in 1965.

F_1-hybrids	Ratings for superficial cracking	
	Immature fruit	Ripe fruit
Sweet Roumanian x NH # 59-4	4.2	3.5
Sweet Roumanian x Red Chili	1.6	2.1
Red Chili x Sweet Roumanian	1.6	2.1
Red Chili x Sweet Cherry	0.8	0.3
Sweet Cherry x Red Chili	1.0	0.1

Table 4. Least-squares analysis of data with unequal subclass numbers of immature and ripe fruits of 26 field-grown varieties in 1964 and 1965.

Analysis of variance: Two-way classification with interaction

Source of variation	d.f.	Mean square	F
Immature fruits:			
varieties	25	854.0789	9.036 **
years	1	18606.7163	196.867 **
varieties x years	25	304.3964	3.220 **
Error	173	94.5138	
Ripe fruits:			
varieties	25	1730.0910	16.067 **
years	1	5258.3707	48.834 **
varieties x years	25	409.8443	3.806 **
Error	193	107.6773	

** significant at the one percent level of probability.

5. The heritability of superficial cracking of pepper fruits

For any accurate classification of phenotypes within populations of pepper plants in which the character for superficial cracking is being considered, it is desireable to have rather complete expression of the defect. One can not be sure, otherwise, whether a plant that merits a 0 rating is genetically free of the abnormality or is merely not manifesting symptoms due to an inadequate environment for expression of the trait. Since in both years ripe fruits rather consistently had more superficial cracking than did the immature fruits, data for the ripe fruits only were used for estimating heritability according to the method of Warner (13). High estimates of heritability for superficial cracking were obtained in both 1964 and 1965 (see Table 5).

Warner (13) stated: "The need for at least several hundred individuals of the F_2, and a like number of the backcrosses, is apparent in order to reduce the sampling error to a practical level".

The numbers of plants listed in Table 5 hardly fulfilled this specification, particularly for the backcrosses. It proved difficult to get enough seeds of the backcross of the F_1 plants and Sweet Roumanian because of failure of the flowers to set fruits. It was somewhat less so for the backcross to the less susceptible parent, NH # 59-4. That the relative magnitude of heritability estimates for a genetic character will vary from year to year and location to location for the same cross is expected. The location in this study was essentially the same in 1964 and 1965. The estimates of heritability in the two years were 0.90 and 0.56, respectively. With reference to appendix Table 1, appreciable differences in soil moisture conditions for the two years were recorded. That water relationships are associated with superficial cracking of the pepper has been noted already in this study. A high estimate of heritability according to Warner's method suggests that the trait is genetically controlled, but does not rule out environmental

effects. The environment was assumed to be similar for the 3 genetic populations grown within a given year. The estimates of heritability for superficial cracking found in this study would seem to make feasible the selection for individual plants in F_2 that were phenotypically free of the defect. Approximately one half of such selections might be expected to have little or no superficial cracking of the fruits. Further study will be necessary to learn how many factors may be involved in the inheritance of this trait, and how effective selection in F_2 from a cross between a susceptible parent and a highly resistant parent can be.

Table 5. Summary of total variances and heritability estimates for superficial cracking of ripe fruits in 3 genetic populations from a cross of Sweet Roumanian and NH # 59-4 peppers.

Year	Superficial cracking of	Observed variances			Estimate of heritability
		Bc_{SR}	Bc_{59-4}	F_2	
1964	Ripe fruits	2.7938	4.3431	6.5144	0.90
	No. of plants	(56)	(62)	(135)	
1965	Ripe fruits	2.2536	1.7745	2.7951	0.56
	No. of plants	(43)	(122)	(216)	

SECTION V

CONCLUSIONS AND SUMMARY

Superficial cracking of pepper fruits was studied. The varying patterns of cracking, parthenocarpic fruits, and incidence of cracking were described and illustrated.

From observations of reciprocal grafts between a highly susceptible and a somewhat resistant variety, it was concluded that the defect was a non-infectious disorder.

Of 32 sweet and 9 pungent commercial varieties observed and studied only Red Chili, a pungent one, remained free of the defect in both 1964 and 1965. Ripe fruits had more severe superficial cracking than did immature fruits. Statistically significant differences were found between varieties, years,and varieties x years when 26 varieties of peppers were tested by the method of least-squares.

Superficial cracking of pepper fruits is a heritable trait as based upon Warner's method for estimating heritability. Effective selection in F_2 from a cross between a susceptible and a highly resistant parent seems possible.

SECTION VI

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SECTION VII

APPENDIX

Table 1. Daily temperatures and precipitation from May 28 to October 7 for 1964 and 1965 in Durham, New Hampshire. 1/

Date		1964			1965		
		Temperature		Precipitation	Temperature		Precipitation
		Max.	Min.		Max.	Min.	
May	28	71	39	T 2/	81	51	0.22
	29	65	32	----	75	46	----
	30	71	36	----	68	37	0.48
	31	73	34	----	70	43	----
June	1	65	55	----	70	36	0.03
	2	68	42	----	66	52	0.47
	3	71	31	----	59	48	0.14
	4	69	45	0.05	75	35	----
	5	70	42	----	83	46	----
	6	76	32	----	86	43	----
	7	80	52	----	90	54	----
	8	71	56	0.84	87	52	----
	9	71	57	0.01	84	65	0.10
	10	87	53	----	84	59	T
	11	85	50	----	77	43	T
	12	84	47	----	80	41	----
	13	80	42	0.04	72	48	2.46
	14	82	41	0.03	55	48	0.31
	15	78	45	T	65	39	T
	16	64	52	----	73	35	----
	17	76	47	T	72	36	----
	18	80	38	----	77	43	T
	19	81	42	----	78	43	0.05
	20	95	62	----	86	55	0.13
	21	95	60	----	90	--	----
	22	86	57	----	88	61	----
	23	87	46	----	91	48	----

Table 1. Continued

Date		1964			1965		
		Temperature		Precipitation	Temperature		Precipitation
		Max.	Min.		Max.	Min.	
June	24	90	55	----	85	66	0.22
	25	79	59	0.17	74	43	T
	26	83	44	----	77	40	----
	27	85	60	----	83	39	----
	28	83	41	----	89	51	----
	29	84	44	----	90	68	----
	30	91	61	0.08	84	60	0.06
July	1	99	60	----	80	49	T
	2	87	62	----	81	41	----
	3	85	61	1.03	78	48	0.17
	4	81	62	0.20	79	52	T
	5	80	57	T	84	47	----
	6	75	56	2.02	74	57	T
	7	83	47	0.01	74	35	----
	8	82	47	----	85	58	0.10
	9	74	58	T	86	48	----
	10	67	58	0.28	85	65	0.10
	11	78	53	----	82	58	----
	12	80	52	----	84	49	----
	13	70	57	0.03	82	49	----
	14	76	56	0.47	94	64	----
	15	88	54	----	90	68	0.18
	16	86	53	----	81	48	----
	17	89	53	----	86	48	0.22
	18	91	58	----	77	62	0.44
	19	91	66	0.30	78	59	0.16
	20	77	58	----	76	42	----
	21	86	57	----	79	43	T
	22	87	69	0.31	82	44	----
	23	79	60	----	78	63	T
	24	69	--	----	87	61	----
	25	69	56	T	90	72	T
	26	77	55	T	86	57	----
	27	90	55	----	82	49	----
	28	92	54	----	80	47	----
	29	86	64	----	82	50	T
	30	81	49	0.01	86	44	----
	31	76	40	----	79	47	----

Table 1. Continued

Date		1964			1965		
		Temperature		Precipitation	Temperature		Precipitation
		Max.	Min.		Max.	Min.	
August	1	79	38	----	82	44	----
	2	71	54	T	68	59	0.05
	3	73	45	T	80	58	0.20
	4	78	46	----	83	44	----
	5	75	52	T	83	44	----
	6	76	51	----	93	49	----
	7	72	42	----	96	63	----
	8	75	54	T	89	68	----
	9	76	41	----	87	69	0.71
	10	79	36	----	87	67	0.47
	11	74	46	T	78	59	0.07
	12	75	69	0.06	86	50	----
	13	76	50	0.01	86	61	----
	14	72	38	----	83	55	----
	15	72	36	T	91	56	----
	16	81	37	----	94	65	----
	17	78	58	T	88	63	----
	18	82	55	T	85	64	0.07
	19	78	57	T	85	67	0.52
	20	77	37	T	80	58	T
	21	75	40	0.48	78	46	----
	22	69	52	1.31	70	52	0.30
	23	61	54	0.39	78	55	0.16
	24	86	52	0.01	79	39	----
	25	82	45	----	82	44	----
	26	80	54	0.04	72	58	0.06
	27	80	40	----	84	59	----
	28	80	42	----	87	54	0.52
	29	81	42	----	65	46	0.20
	30	85	51	----	64	34	----
	31	84	59	----	64	28	----
September	1	78	57	T	71	47	0.28
	2	75	36	----	72	52	0.31
	3	76	36	----	74	42	----
	4	79	48	0.04	74	38	----
	5	82	54	----	73	37	----
	6	78	53	----	80	38	----
	7	78	44	----	76	51	----

Table 1. Continued

Date		1964 Temperature Max.	1964 Temperature Min.	1964 Precipitation	1965 Temperature Max.	1965 Temperature Min.	1965 Precipitation
September	8	85	39	----	73	45	0.05
	9	80	60	0.02	71	34	----
	10	71	59	T	87	53	0.20
	11	90	54	----	80	64	----
	12	72	51	0.04	63	40	----
	13	63	38	T	64	39	0.76
	14	60	38	0.03	66	48	0.02
	15	67	28	T	66	46	0.10
	16	68	29	----	75	55	----
	17	66	31	0.03	75	48	----
	18	76	40	T	78	47	T
	19	66	35	----	68	56	0.16
	20	66	29	T	84	55	----
	21	69	30	T	88	65	----
	22	70	41	T	91	67	----
	23	70	57	0.45	88	64	----
	24	79	68	T	81	60	----
	25	72	36	----	73	51	0.19
	26	72	31	T	72	33	----
	27	74	39	----	62	41	T
	28	70	45	0.02	59	25	----
	29	55	36	0.11	63	44	0.02
	30	66	43	T	57	31	----
October	1	61	30	T	63	35	0.57
	2	64	25	T	67	42	0.11
	3	71	50	0.13	64	28	0.01
	4	74	31	----	56	35	----
	5	68	45	----	45	32	T
	6	56	24	----	51	22	----
	7	56	27	T	60	52	----

1/ Data provided by Department of Soil and Water Science, University of New Hampshire.

2/ T = trace.

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